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UTILITY PATENT APPLICATION TRANSMITTAL

(Only for new nonprovisional applications under 37 CFR 1.53(b))

Attorney Docket	390086.94677
First Inventor	Gopal B. Avinash
Title	Method and Apparatus For Extracting A Left Ventricular Endocardium From MR Cardiac Images
Express Mail Label No.	EJ 636 886 711 US

JC825 U.S. PTO 09/716216 11/22/00

APPLICATION ELEMENTS

See MPEP Chapter 600 concerning utility patent application contents.

ADDRESS TO: **Commissioner for Patents, Box Patent Application, Washington, D.C. 20231**

1. [X] Fee transmittal Form (Submit an original and a duplicate for fee processing)
2. [ ] Applicant claims small entity status See 37 CFR 1.27.
3. [X] Specification [Total Pages 27] *(preferred arrangement set forth below)*
   - Descriptive title of the invention
   - Cross References to Related Applications
   - Statement Regarding Fed Sponsored R&D
   - Reference to sequence listing, a table or a computer program listing appendix
   - Background of the Invention
   - Brief Summary of the Invention
   - Brief Description of the Drawings *(if filed)*
   - Detailed Description
   - Claim(s)
   - Abstract of the Disclosure
4. [X] Drawing(s) (35 USC 113) [Total Sheets 8]
5. Oath or Declaration [Total Pages 3]
   a. [ ] Newly executed (original or copy)
   b. [ ] Copy from prior Application (37 CFR 1.63(d)) (for continuation/divisional with Box 17 completed)
      i. [ ] DELETION OF INVENTOR(S) Signed Statement attached deleting inventor(s) named in prior application, see 37CFR 1.63(d)(2) and 1.33(b).
6. [ ] Application Data Sheet. See 37 CFR 1.76
7. [ ] CD-ROM or CD-R in duplicate, large table or Computer Program (Appendix)
8. Nucleotide and/or Amino Acid Sequence Submission (if applicable, all necessary)
   a. [ ] Computer Readable Form (CRF)
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ACCOMPANYING APPLICATION PARTS

9. [ ] Assignment Papers (cover sheet & documents)
10. [ ] 37 CFR 3.73(b) Statement (where there is an assignee) [ ] Power of Attorney
11. [ ] English Translation Document *(if applicable)*
12. [ ] Information Disclosure Statement (IDS)/PTO-1449 [ ] Copies of IDS Citations
13. [ ] Preliminary Amendment
14. [X] Return receipt postcard (MPEP 503) *(Should be specifically itemized)*
15. [ ] Certified copy of priority Document(s) *(if foreign priority is claimed)*
16. [ ] Other:

17. **If a CONTINUING APPLICATION**, check appropriate box and supply the requisite information: and in a preliminary amendment or in an Application Data Sheet under 37 CFR 1.76

[ ] Continuation [ ] Divisional [ ] Continuation-in-part (CIP) of prior application no. ____/____

Prior application information: Examiner: Group/Art Unit:

For CONTINUATION OR DIVISIONAL APPS only: The entire disclosure of the prior application, from which an oath or declaration is supplied under Box 5b, is considered a part of the disclosure of the accompanying continuation or divisional application and is hereby incorporated by reference. The incorporation can only be relied upon when a portion has been inadvertently omitted from the submitted application parts.

18. CORRESPONDENCE ADDRESS

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Signature	Adam J. Forman	Date: November 22, 2000	

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FEE TRANSMITTAL for FY 2001

Patent fees are subject to annual revision.

TOTAL AMOUNT OF PAYMENT	$710.00

Complete if Known	
Application Number	
Filing Date	November 22, 2000
First Named Inventor	Gopal B. Avinash
Group Art Unit	
Examiner Name	
Attorney Docket Number	390086.94677

METHOD OF PAYMENT (check one)

1. [X] The Commissioner is hereby authorized to charge indicated fees and credit any over payments to:

Deposit Account Number: 17-0055

Deposit Account Name: Quarles & Brady LLP

[X] Charge Any Additional Fee Required Under 37 CFR 1.16 and 1.17

[ ] Applicant claims small entity status See 37 CFR 1.27

2. [ ] Payment Enclosed:

[ ] Check [ ] Credit Card [ ] Money Order [ ] Other

FEE CALCULATION

1. BASIC FILING FEE

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description	Fee Paid
101	710	201	355	Utility filing fee	710.00
106	320	206	160	Design filing fee	
107	490	207	245	Plant filing fee	
108	710	208	355	Reissue filing fee	
114	150	214	75	Provisional filing fee	

SUBTOTAL (1) ($)710.00

2. CLAIMS

		Extra		Fee from below		Fee Paid
Total Claims	17	-20**=		X	=	
Independent	2	-3**=		X	=	
Multiple Dependent Claims					=	

** or number previously paid, if greater, For reissues see below

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description
103	18	203	9	Claims in excess of 20
102	80	202	40	Independent claims in excess of 3
104	270	204	135	Multiple dependent claim
109	80	209	40	**Reissue independent claims over original patent
110	18	210	9	**Reissue claims in excess of 20 and over original patent

SUBTOTAL (2) ($).00

FEE CALCULATION (continued)

3. ADDITIONAL FEES

Large Entity Fee Code	Large Entity Fee ($)	Small Entity Fee Code	Small Entity Fee ($)	Fee Description	Fee Paid
105	130	205	65	Surcharge - late filing fee or oath	
127	50	227	25	Surcharge - late provisional filing fee or cover sheet	
139	130	139	130	Non-English specification	
147	2,520	147	2,520	For filing a request for reexamination	
112	920	112	920	Requesting publication of SIR prior to Examiner action	
113	1,840	113	1,840	Requesting publication of SIR after Examiner action	
115	110	215	55	Extension for reply within first month	
116	390	216	195	Extension for reply within second month	
117	890	217	445	Extension for reply within third month	
118	1,390	218	695	Extension for reply within fourth month	
128	1,890	228	945	Extension for reply within fifth month	
119	310	219	155	Notice of Appeal	
120	310	220	155	Filing a brief in support of an appeal	
121	270	221	135	Request for oral hearing	
138	1,510	138	1,510	Petition to institute a public use proceeding	
140	110	240	55	Petition to revive unavoidably abandoned application	
141	1,240	241	620	Petition to revive unintentionally abandoned application	
142	1,240	242	620	Utility issue fee (or reissue)	
143	440	243	220	Design issue fee	
144	600	244	300	Plant issue fee	
122	130	122	130	Petitions to the Commissioner	
123	50	123	50	Petitions related to provisional applications	
126	240	126	240	Submission of Information Disclosure Stmt	
581	40	581	40	Recording each patent assignment per property (times number of properties)	
146	710	246	355	Filing a submission after final rejection (37 CFR 1.129(a))	
149	710	2496	355	For each additional invention to be examined (37 CFR 1.129(b))	
179	710	270	355	Request for Continued Examination (RCE)	
169	900	169	900	Request for expedited examination of a design application	

Other fee (specify) _____

* Reduced by Basic Filing Fee Paid

SUBTOTAL (3) ($).00

SUBMITTED BY	#4655829			Complete (if applicable)	
Typed or Printed Name	Adam J. Forman	Registration No. (Attorney/Agent)	46,707	Telephone	(414) 277-5405

METHOD AND APPARATUS FOR EXTRACTING A LEFT VENTRICULAR ENDOCARDIUM FROM MR CARDIAC IMAGES

BACKGROUND OF THE INVENTION

The present invention relates generally to nuclear magnetic resonance imaging methods and systems, and in particular, relates to segmentation of a human internal organ, or a portion of an internal organ, for example a left ventricular endocardium.

When a substance such as human tissue is subjected to a uniform magnetic field (polarizing field B_0), the individual magnetic moments of the spins in the tissue attempt to align with this polarizing field, but precess about it in random order at their characteristic Larmor frequency. If the substance, or tissue, is subjected to a magnetic field (excitation field B_1) which is in the x-y plane and which is near the Larmor frequency, the net aligned moment, M_z, may be rotated, or "tipped", into the x-y plane to produce a net transverse magnetic moment M_t. A signal is emitted by the excited spins after the excitation signal B_1 is terminated, this signal may be received and processed to form an image.

When utilizing these signals to produce images, magnetic field gradients (G_x G_y and G_z) are employed. Typically, the region to be imaged is scanned by a sequence of measurement cycles in which these gradients vary according to the particular localization method being used. The resulting set of received NMR signals are digitized and processed to reconstruct the image using one of many well-known reconstruction techniques.

Most NMR scans currently used to produce medical images require many minutes to acquire the necessary data. The reduction of this scan time is an important consideration since reduced scan time increases

patient throughput, improves patient comfort, and improves image quality by reducing motion artifacts. There is a class of pulse sequences which have a very short repetition time (TR) and result in complete scans which can be conducted in seconds rather than minutes. When applied to cardiac imaging, for example, a complete scan from which a series of images showing the heart at different phases of its cycle can be acquired in a single breath-hold.

The prognosis of patients with a wide variety of cardiac diseases (including coronary artery disease, valvular heart disease, congestive heart failure and cardiac arrhythmias) has been closely linked to the performance of the heart as indicated by measurements such as wall thickening, wall motion, and myocardial mass. Accurate quantitative measures of regional contractile function could therefore have significant prognostic and therapeutic importance. For example, many patients with severe coronary artery disease may have normal regional and global left ventricular function at rest but have abnormalities induced by stress. In clinical practice, patients with coronary artery disease can be detected by stress echocardiography based on new functional deficits during stress. However, interobserver variability of this type of qualitative measure is an inherent limitation that could be improved with quantitative measures. Thus, there is a need for high quality quantitative measures of regional cardiac function.

Segmentation of the left ventricle in MR images is therefore a fundamental step in analyzing the performance of the heart. MR image data of the endocardium is currently acquired by applying a specific sequence of RF pulses to yield a NMR signal that provides information pertaining to the tissue under test. A particular pulse sequence can therefore be applied to obtain an image of pixels in the intensity range of, for example, a cross-section of the left ventricle tissue. Current processes are available for segmenting the epicardium, but they lack robustness and are difficult to use.

Segmentation methods that are currently available include snake-based techniques such as that described by A. Yezzi, et al. "A Geometric Snake Model for Segmentation of Medical Imagery," IEEE Transaction on Medical Imaging, 16, 199-209 (April, 1997). Snakes, also known as active contours, have been used in an attempt to segment features of the left ventricle. Snakes are described by a parameterized curve whose evolution is determined by the minimization of an energy field. The equation of the energy field, as defined by J. C. Gardner et al. "A Semi-Automated Computerized System for Fracture Assessment of Spinal X-Ray Films," Proceedings of the International Society for Optical Engineering, 2710, 996-1008 (1996), is:

$$E[\vec{x}(s)] \equiv k \int_0^1 ds \left[\frac{1}{2}\alpha\left(\frac{d\vec{x}}{ds}\right)^2 + \frac{1}{2}\beta\left(\frac{d^2\vec{x}}{ds^2}\right)^2 - \gamma H(\vec{x}(s)) \right] \quad (1)$$

where s is the parameterization variable, $\vec{x}$ is the parameterized curve, κ is the normalization constant, α is the $H(\vec{x}) = \left|\vec{\nabla} I(\vec{x})\right|$ tension of the snake, β is the rigidity of the snake, γ controls the attraction to image features, and I is the pixel intensity of the image. H(x) refers to a function which defines the features that attract the snake algorithm to the boundary and, typically, is chosen to be the magnitude of the gradient of the image intensity.

Because the magnitude of the gradient is used to attract the algorithm to the boundary of the left ventricle, the snake does not work well where the boundary is defined by edges that are weak in intensity. In order for the snake algorithm to attach to a boundary, a user must intervene and supply a boundary condition to define the proximity of the boundary for the snake. This is undesirable because the user may need to interact with the segmentation algorithm while the images are being processed. Snake

based techniques can be used, as described by Yezzi, to produce a geometric snake model having a stopping term and a constant inflation term added to the evolution equation. The resulting evolution equation of the Yezzi active contour model is:

$$\frac{\partial \Psi}{\partial t} = \phi \|\nabla \Psi\| (\kappa + \nu) + \nabla \phi * \nabla \Psi \qquad (2)$$

where v is a constant inflation force, $\kappa \equiv div\left(\frac{\nabla \psi}{\|\nabla \psi\|}\right)$ is the curvature of the level sets of $\psi(x, y, t)$, ϕ is a function dependent on the type of image and is a stopping term for the curve evolution. Snake based techniques are additionally unfavorable because they rely primarily on edge information only, and therefore are subject to greater error and generally lack robustness, particularly in a clinical setting. S. Ranganath attempted unsuccessfully to segment an endocardium using a snake, as described in "Contour Extraction from Cardiac MRI Studies Using Snakes," IEEE Transactions on Medical Imaging, 14(2), 328-338 (June, 1995).

Another such method currently used in conjunction with attempted detection of endocardial boundaries is a shape-based technique known as the MR Analytical Software System (MASS), introduced by R. J. van der Geest et al. "Comparison Between Manual and Semiautomated Analysis of Left Ventricular Volume Parameters from Short-Axis MR Images," Journal of Computer Assisted Tomogrophy," 21(5), 756-675 (1997), which uses shape as the central principal for the detection of the epicardial and endocardial contours. The MASS algorithm operated by first using a Hough transform, well known in the art, to determine the initial search location for the endocardial and epicardial boundaries. The Hough transform produces a map with high values near the center of approximately circular objects in the

original image. A size constraint is then used to narrow a search for circular areas in the image corresponding to the first cardiac phase. After the search determines which circular areas constitute the boundary areas, a line is fit through the Hough images to estimate the center of the left ventricle. The line provides an estimate of the longitudinal axis of the heart.

The MASS algorithm then transforms each image in the study to a polar image and computes a polar edge image. Using a circle estimation from the original image, the intensity of edges in the radial direction, an estimate for myocardial wall thickness, and a maximum likelihood estimate of the endocardial and epicardial radii are calculated. If a satisfactory estimate is not found for the epicardial radius, one is created afterward through linear interpolation between adjacent radii. Once the epicardial boundary has been determined, MASS uses an intensity thresholding technique to find the endocardial boundary. However, because shape-based techniques primarily rely on the shape of the image to produce the outer edge pattern, these methods, like the snake, are subject to error and generally lack robustness.

What is therefore needed is a method and apparatus for segmenting an epicardium in an image that relies on several information sources to produce an image of the left ventricular epicardial boundary that is clinically robust and that operates with greater accuracy than conventional techniques and that requires only minimal user interaction.

SUMMARY OF THE INVENTION

The present invention relates to a system and method for segmenting a human organ, and in particular, a left ventricular endocardium using a method that relies on image shape, size, gradients, intensity, and connectivity, and requires only minimal user input to provide a clinically robust mask image of the endocardium of a human heart.

In accordance with a first aspect of the invention, a method for extracting an image acquired with a medical imaging system to identify the boundary of an organ includes acquiring image data of the organ, and subsequently reconstructing an image corresponding generally to the organ. Next, a starting location is selected on the reconstructed image within the confines of the boundary of the organ. Next, an expansion boundary is iteratively propagated around the starting location outwardly a plurality of times until it is determined that the expansion boundary has traversed the boundary of said organ. Finally, a representation of the boundary of the organ is output to a user.

BRIEF DESCRIPTION OF THE DRAWINGS

Reference is hereby made to the following figures in which like reference numerals correspond to like elements, and in which:

Fig. 1 is a block diagram of an MRI system which employs the preferred embodiment of the present invention;

Fig. 2 is a flow chart of the steps performed by the MRI system illustrated in Fig. 1 to carry out an endocardial segmentation process in accordance with the preferred embodiment;

Fig. 3 is a flow chart of the steps performed to carry out the image smoothing step of the endocardial segmentation process illustrated in Fig. 2;

Fig. 4 is a flow chart of the steps performed to carry out the parameter initialization step of the endocardial segmentation process illustrated in Fig. 2;

Fig. 5 is a flow chart of the steps performed to carry out the iterative region growing step of the endocardial segmentation process illustrated in Fig. 2;

Fig. 6 is a flow chart of the steps performed to carry out the mask refining step of the iterative region growing process illustrated in Fig. 5;

Fig. 7 is an illustration of a box car filter used to carry out the image smooth image step illustrated in Fig. 3;

Fig. 8 is a schematic map corresponding generally to a nuclear magnetic resonance image of a chest cavity in accordance with the preferred embodiment;

Fig. 9A is a mask representing a plurality of "on" pixels used during the iterative region growing step illustrated in Fig. 5;

Fig. 9B is the mask of Fig. 9A having unconnected "on" pixels and thin lines removed in accordance with the preferred embodiment;

Fig. 9C is the mask of Fig. 9B having the outer ring extracted.

Fig. 10 a flow chart of the steps performed to carry out the thin line removal step of the iterative region growing process illustrated in Fig. 5;

Fig. 11 is a schematic illustration of stopping criteria used during the iterative region growing process illustrated in Fig. 5;

Fig. 12 is a flow chart of the steps performed to carry out the final refinements step of the iterative region growing process illustrated in Fig. 5;

Fig. 13 is an illustration of statistical data acquired during the endocardial segmentation process in accordance with the preferred embodiment;

Fig. 14 is a graphical representation of the data acquired in Fig. 13; and

Fig. 15 is an illustration of the output mask produced during the final refinements step illustrated in Fig. 12 reflecting the data acquired in Fig. 13.

GENERAL DESCRIPTION OF THE INVENTION

An endocardial segmentation process is performed on an acquired MR image by an image processor using image shape, gradients, intensity, and connectivity.

In particular, a seed point in the blood pool mask having a sufficiently high intensity value is selected. It should be appreciated that the term "blood pool" as used in accordance with the preferred embodiment refers to the blood mass inside the left ventricular chamber of the heart. An iterative process ensues that takes advantage of the fact that the pixel intensities will vary in a predictable manner throughout the blood pool. In particular, the intensities are expected to increase significantly at the endocardial boundary.

A binary map is created corresponding to the image having a seed pixel of high intensity selected. Next, the map is dilated such that pixels surrounding the seed pixel are turned "on" whose intensities are greater than a predetermined threshold intensity value. The map is refined, and subsequent dilations and refinements are preformed with the threshold intensity value decreasing with each iteration. Accordingly, the expansion boundary of the mapped image propagates outwardly towards the endocardial boundary.

The mean and standard deviation of the resulting intensity values of the resulting image corresponding to the boundaries are calculated and stored for each iteration. The dilations repeat until the expansion boundary grows beyond the endocardium, and into the other areas surrounding the heart. As the boundary moves beyond the endocardial wall, the boundary should encounter an increase in intensity due to the different tissue compositions of the regions beyond the endocardium. The behavior of the calculated standard deviation will reflect the boundary advancing from the endocardium and into the myocardium. The changes in standard deviation as each iteration is performed therefore provides a relatively accurate approximation of the region containing the endocardial boundary.

Once the statistical computations indicate that the expansion boundary has propagated past the endocardial boundary, final refinements are made to the image to produce an output mask of the blood pool. The outer contour of the blood pool, of course, defines the contour of the endocardial boundary. Once the endocardial boundary is produced, a smoothing process may performed to create a smooth curve representing the endocardial boundary of the left ventricle, if so desired. Additionally, the image corresponding to the endocardial boundary may be produced for observation by the user.

Furthermore, the method in accordance with the preferred embodiment produces an error message if the statistics do not show the expansion boundary crossing the endocardial boundary after a predetermined number of iterations, or if the size of the expansion boundary becomes too large, indicating that it has likely traversed the endocardial boundary.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring initially to Fig. 1, there is shown the major components of a preferred magnetic resonance imaging (MRI) system which incorporates the present invention. The operation of the system is controlled from an operator console 100 which includes a keyboard and control panel 102 and a display 104. The console 100 communicates through a link 116 with a separate computer system 107 that enables an operator to control the production and display of images on the screen 104. The computer system 107 includes a number of modules which communicate with each other through a backplane 118. These include an image processor module 106, a CPU module 108 and a memory module 113, known in the art as a frame buffer for storing image data arrays. The computer system 107 is linked to a disk storage 111 and a tape drive 112 for storage of image data and programs, and it communicates with a separate system control 122 through a high speed serial link 115.

The system control 122 includes a set of modules connected together by a backplane. These include a CPU module 119 and a pulse generator module 121 which connects to the operator console 100 through a serial link 125. It is through this link 125 that the system control 122 receives commands from the operator which indicate the scan sequence that is to be performed. The pulse generator module 121 operates the system components to carry out the desired scan sequence. It produces

data which indicates the timing, strength and shape of the RF pulses which are to be produced, and the timing of and length of the data acquisition window. The pulse generator module 121 connects to a set of gradient amplifiers 127, to indicate the timing and shape of the gradient pulses to be produced during the scan. The pulse generator module 121 also receives patient data from a physiological acquisition controller 129 that receives signals from a number of different sensors connected to the patient, such as ECG signals from electrodes or respiratory signals from a bellows. And finally, the pulse generator module 121 connects to a scan room interface circuit 133 which receives signals from various sensors associated with the condition of the patient and the magnet system. It is also through the scan room interface circuit 133 that a patient positioning system 134 receives commands to move the patient to the desired position for the scan.

The gradient waveforms produced by the pulse generator module 121 are applied to a gradient amplifier system 127 comprised of G_x, G_y and G_z amplifiers. Each gradient amplifier excites a corresponding gradient coil in an assembly generally designated 139 to produce the magnetic field gradients used for position encoding acquired signals. The gradient coil assembly 139 forms part of a magnet assembly 141 which includes a polarizing magnet 140 and a whole-body RF coil 152. A transceiver module 150 in the system control 122 produces pulses which are amplified by an RF amplifier 151 and coupled to the RF coil 152 by a transmit/receive switch 154. The resulting signals radiated by the excited nuclei in the patient may be sensed by the same RF coil 152 and coupled through the transmit/receive switch 154 to a preamplifier 153. The amplified NMR signals are demodulated, filtered, and digitized in the receiver section of the transceiver 150. The transmit/receive switch 154 is controlled by a signal from the pulse generator module 121 to electrically connect the RF amplifier 151 to the coil 152 during the transmit mode and to connect the preamplifier 153 during the receive mode. The transmit/receive switch 154 also enables

a separate RF coil (for example, a head coil or surface coil) to be used in either the transmit or receive mode.

The NMR signals picked up by the RF coil 152 are digitized by the transceiver module 150 and transferred to a memory module 160 in the system control 122. When the scan is completed and an entire array of data has been acquired in the memory module 160, an array processor 161 operates to Fourier transform the data into an array of image data. It should be appreciated that while the Fourier transform is used in accordance with the preferred embodiment, other suitable techniques could be used. This image data is conveyed through the serial link 115 to the computer system 107 where it is stored in the disk memory 111. In response to commands received from the operator console 100, this image data may be archived on the tape drive 112, or it may be further processed by the image processor 106 and conveyed to the operator console 100 and presented on the display 104.

For a more detailed description of the transceiver 150, reference is made to U.S. patent No. 4,952,877 and 4,922,736, which are incorporated herein by reference.

The MRI system of Fig. 1 performs a series of suitable pulse sequences to collect sufficient NMR data so as to produce an image of the left ventricle, as is well known in the art. Fig. 8 illustrates a schematic representation of a typical chest cavity image identifying a human heart 168 having a left ventricle 170, a blood pool 172, and an epicardium 174 The outer contour of the blood pool 172 defines the endocardial boundary 173. A lung field 176 surrounds or partially surrounds the heart 168.

Referring now to Fig. 2, an endocardial segmentation process 200 in accordance with the preferred embodiment endocardial is performed on the

acquired image data by the image processor 106. The first step indicated at process block 202 corrects the image for intensity fall off that was produced while acquiring image data. As is well known to those having ordinary skill in the art, the intensity of the resulting image decreases exponentially with increasing distances between the organ being sampled and the imaging coils. Methods of pre-processing acquired images to remove intensity gradients due to intensity fall off are described, for example, in U.S. Patent No. 5,943,433, entitled "Method for Correcting Inhomogeneity of Spacial Intensity in an Acquired MR Image" and also in pending U.S. patent Application Serial No. 09/317,416, and entitled "Method and Apparatus for Enhancing and Correcting Digital Images" filed May 24, 1999, the disclosures of which are incorporated by reference.

Next process block 204 smoothes the data from the intensity corrected image produced during step 202. In particular, referring to Fig. 3, the corrected cardiac data intensity data for each pixel I(x,y) ,corresponding to the image as corrected during step 202, is read and stored. The image may comprise the entire acquired image, but should extend beyond the endocardial boundary by a sufficient amount so as to ensure that the entire endocardium is included during subsequent operations, as will be described in more detail below. Next, at process block 212, a point on the image is selected as a seed point. In particular, the seed point is chosen by examining the blood pool and selecting a point on the image that consistently corresponds to the blood pool even while the position of the heart changes during systole and diastole. This assures that the seed point resides within the confines of the endocardial boundary. Additionally, the seed point should additionally not be located too close to the endocardial boundary to permit subsequent operations to take place without error.

Next, referring also to Fig. 7, a filter 216 is applied to the input data I(x,y) at process block 214. In particular, filter 216 is a 5X5 box-car filter whose center 218 is placed over the pixel to be averaged. The intensity

values of the selected 25 pixels are averaged as the sum of 1/25 of the intensity value at each pixel. The pixel corresponding to the center 218 is updated with that average. The filter 216 is moved across each pixel of the entire image to produce a smoothed image S(x,y). It should be appreciated that while a box-car is implemented in accordance with the preferred embodiment, any method capable of smoothing an acquired MR image may be used. Additionally, as will become apparent from the description below, while the "intensity correction" and "smooth image" processes improve the reliability of the endocardial segmentation process, they are not essential to the operation of the preferred embodiment.

Once the image has been smoothed at step 204, process 200 proceeds to process block 206 to initialize various parameters that will be used during the subsequent processes of the preferred embodiment. Referring now to Fig. 4, process 206 begins at step 220, whereby a plurality of pixels are chosen that are disposed within a predetermined proximity of the previously selected seed point. A new seed pixel 300 (illustrated in Fig. 9A) is chosen as the pixel of highest intensity within the selected plurality of pixels. The plurality of pixels is selected using an 8X8 array of pixels that surrounds the previously selected seed point in accordance with the preferred embodiment, though it should be appreciated that any suitable alternative array could be used. The new seed pixel 300 will therefore fall within the 8X8 array. The intensity of the new seed pixel 300 is stored as "Seed_I" and the seed pixel 300 is plotted on binary mask 302. It should be appreciated that Figs. 9A-C are examples of a portion of a binary map, and does not necessarily correspond to an actual MR image. Rather, the mask 302 is being used to illustrate the various operations that are performed in accordance with the preferred embodiment.

Next, at step 222, a first mean intensity value (MEAN_1) is calculated as the average intensity of those pixels falling within a first neighborhood surrounding the seed pixel. The first mean intensity value is also stored

permanently in Initial_Mean_1. In accordance with the preferred embodiment, the first neighborhood is chosen as a 6X6 array of pixels surrounding the seed pixel. Process 206 then proceeds to step 224 and calculates a second mean intensity value (MEAN_2) as the average intensity of those pixels falling within a second neighborhood that is chosen to be significantly larger than the first neighborhood. In accordance with the preferred embodiment, the second neighborhood is selected as a 60X60 array of pixels surrounding the seed pixel. It is appreciated that the second neighborhood may include areas surrounding the endocardium. This is not a concern, however, as the neighborhood is sufficiently large so as to withstand intensity variations that occur at the endocardial boundary and beyond.

At step 226, an intensity decrement factor (DI) is selected which, in part, determines the rate at which the boundary of the mask will advance during subsequent dilation operations. It has been empirically determined that DI=.07 is sufficient, however, it should be appreciated that suitable alternative values could be chosen, whereby smaller DI values will result in smaller boundary advancements during the dilation iterations to follow. Finally, at step 228, the Iteration_Number is set to a value of 1 in anticipation of the first "Iterative Region Growing" step 208, which is the final step in the Endocardial Segmentation Process 200.

Referring now to Fig. 5, the "Iterative Region Growing" process 208 begins at step 230, where the mask is refined to produce a first contour that will be propagated outwardly in search of the endocardial boundary. The refinement process 230 is illustrated in Fig. 6, and begins at step 252, where a given pixel in the smooth mask is selected for examination. At decision block 254, the pixel intensity of the selected pixel is compared to the intensity value of Mean_1. If the pixel intensity is greater than that of Mean_1, that pixel is turned on at step 256. Otherwise, the pixel is turned off at step 258. The process then proceeds to decision block 260 and

determines if all pixels on the mask have been examined. If not, the process reverts to step 252 and continues until all pixels have been examined. Accordingly, any pixel on the mask having a value greater than the small neighborhood average intensity value will be turned on. These pixels may or may not be connected to the seed pixel and, in this regard, they may or may not be disposed within the endocardial boundary. Fig. 9A illustrates those pixels 304 whose intensities are greater than Mean_1.

Once the entire mask has been refined, step 262 sets a parameter "Old_Count" equal to "Count" for all iterations greater than 1. As will become more apparent from the description below, "Count" is a measure of the size of the propagating outer boundary, and will trigger an error message if the boundary becomes too large. "Old_Count" will operate as the boundary size for the previous iteration when "Count" is subsequently updated. Next, step 264 reverts the process 230 to step 232 of the "Iterative Region Growing" process 208.

At step 232, a "Thin Line Removal" step is performed on the refined mask 302, as illustrated in more detail in Fig. 10. Process 232 begins at step 266, where an erosion operation is performed on the refined mask 302. Specifically, the erosion step 266 turns all pixels off that are adjacent an "off" pixel. This will remove the thin line 306 extending from the structure of "on" pixels 308, and will additionally remove the outer layer of the structure 308. Next, at step 268, any "on" pixels that are not connected to the seed pixel, either directly or via other "on" pixels, are removed. For example, in Fig. 9A, this removal step would include the innermost pixel 310, as ring 312 would have been removed in the previous erosion step 266. Accordingly, step 268 will ensure that the resulting propagating boundary will be disposed within the endocardium. Steps 266 and 268 thereby produce an inner core of "on" pixels 314 as illustrated in Fig. 9B.

Next, at step 270, a dilation operation is performed that will turn on those pixels adjacent an "on" pixel. Therefore, a dilated image 318 is produced having an outer ring 316 that surrounds an inner core 314. Accordingly, as may be observed by comparing Figs. 9A and 9B, the thin line 206 and unconnected group of "on" pixels 310 and 312 have been removed from the mask, thereby allowing for subsequent iterations within the endocardium. Next, at step 272, those pixels comprising the inner core 314 and outer ring 316 are counted and stored as "Count". For example, a value of 28 would be stored into "Count" for the image illustrated in Fig. 9B.

Referring again to Fig. 5, at step 234, process 208 extracts the outer ring 316 from the image 318. This is achieved by performing the above-described erosion operation on the image 318 to remove the outer ring 316. Next, the remaining inner core 314 is subtracted from the image 318 to produce the outer ring 316 illustrated in Fig. 9C. It will be appreciated from the description that follows that the outer ring 316 comprises a boundary that will advance outwardly and across the endocardium in accordance with the preferred embodiment.

Next, at step 236, a statistical computation is performed on the outer ring 316. Specifically, Mean_3 is calculated for the present iteration, which is the mean intensity for all those "on" pixels making up the outer ring 316. The standard deviation SD is also calculated for the ring 316 at step 236.

Next, at step 238, the process 208 determines whether a "Stop" condition exists at decision block 238. The two possible stop conditions are illustrated with reference to Fig. 11. In particular, a first and/or a second condition must be present with a third condition in order to stop the endocardial segmentation process 200. The first condition is met when the Count value has exceeded an empirically derived predetermined maximum number, thereby signifying that the size of the image has increased to the point that it should have crossed the endocardial boundary. It has been

determined that a maximum Count of 3000 may be used for this purpose. The second condition is met when the standard deviation (SD) has exceeded an empirically derived predetermined value. This condition will indicate variance in the intensity of the outer ring 316 consistent with the outer ring traversing the endocardial boundary. A predetermined value of 8.0 has been found to work In accordance with the preferred embodiment, though it should be appreciated to one having ordinary skill in the art that alternative suitable values could suffice.

The third condition that must be present along with at least one of the first and second conditions to trigger the stop condition at decision block 238 is fourfold. First, the iteration number must be greater than 2. Next, the mean intensity of the outer ring 316 (Mean_3) must be greater than the mean intensity of the outer ring 316 of the previous iteration (Mean_3_Old). Next, the mean intensity of the outer ring 316 of the previous iteration must be less than one-half the sum of the intensity of the seed pixel and the large neighborhood intensity (Mean_2) calculated during step 224. Finally, the standard deviation for the outer ring 316 (SD) must be greater than the standard deviation for the outer ring 316 calculated during the previous iteration (SD_Old). If it is determined at decision block 238 that a "stop" condition exists, process 208 proceeds to step 246, wherein final refinements are made to the mask, as will be described in further detail below.

If, however, it is determined that the "stop" condition is not met, either due to the absence of both the first and second conditions, or the absence of the third condition, process 208 updates various parameters at step 240 in anticipation of the next iteration. First, MEAN_1 is updated to equal Initial_Mean_1*(1 - DI*Iteration_Number). In the next iteration, as described above, the threshold criteria depend on the value of Mean_1 such that lower DI values produce more inclusive mask refinements at step 230, thereby

propagating the outer ring 316 outwardly at a greater rate. Next, Mean_3_Old and SD_Old are updated as the current mean and standard deviation for the outer ring 316, respectively, that will be used during the next iteration. Additionally, Iteration_Number is incremented by 1.

Next a determination is made whether the endocardial segmentation process 200 has failed at decision block 242. In particular, one of two conditions will trigger an error. The first error condition occurs when Old_Count is greater than the maximum size. This error condition indicates that the outer ring 316 had exceeded the maximum size during the previous iteration, and the present iteration, but that the statistics did not indicate that the outer ring 316 traversed the endocardial boundary, as determined using the third condition in Fig. 11. The second error condition occurs when Iteration_Number has exceeded an empirically derived predetermined maximum acceptable value. In accordance with the preferred embodiment, the maximum number of iterations has been chosen to equal 40, though one having ordinary skill in the art appreciates that this number may differ. If either of these error conditions are present at decision block 242, process 208 will display an error message to the user at step 244. Information regarding the cause of the error message my additionally be output if so desired. Finally, the endocardial segmentation process 200 will terminate at step 250.

Otherwise, if no error is present at decision block 242, process 208 reverts to step 230 to perform an additional iteration. Subsequent iterations are performed until a satisfactory result is achieved, or an error is produced.

As discussed above, if the process 208 determines at decision block 238 that a stop condition exists, thereby signifying that the outer ring 316 has traversed the endocardial boundary, final refinements are made to the image at step 246. Specifically, referring to Fig. 12, the refinement process

246 begins at decision block 274, and updates Mean_1 in anticipation of a final thresholding operation. If Mean_3_Old > 0, Mean_1 is updated to the mean intensity value of the outer ring 316 at the previous iteration (Mean_3_Old) at step 278. (Mean_3_old could be less than 0, for example, if for example, the outer ring is disposed in an area of backflow in the blood pool.) Otherwise, at step 278, Mean_1 is updated to the mean intensity value of the large neighborhood boundary (Mean_2), as determined during the parameter initialization process 208. If, however, it is determined at decision block 280 that Mean_3_Old > than Mean_3, then Mean_1 is updated to Mean_3.

Next, at step 284, the mask is updated to turn all pixels on whose intensities are greater than Mean_1. All other pixels are turned off. The update step 284 essentially retracts the expansion boundary, which has already crossed the endocardial boundary, as indicated by the statistics at decision block 238. At step 286, all thin lines and pixels that are unconnected to the seed pixel are removed, as discussed above with reference to steps 266-270.

At step 288, the mask is copied and written to an output mask, which will produce the endocardial contour for the user. First, the output mask is inverted, such that all "on" pixels and turned off, and vice versa. Next, at step 290, a 4-connectedness operation is performed turn off those pixels that do not have neighboring "on" pixels to the north, south, east and west. At step 292, the remaining groups of pixels are examined to determine whether those groups are of a sufficient size. Accordingly, those groups of "on" pixels that are unconnected to the seed pixel, and that are less than a predetermined size, for example 150 pixels (islands) are turned off. The output mask is once again inverted so as to once again turn on those pixels that were on before the previous inversion. Additionally, the second inversion turns on those small clusters that did not meet the final

thresholding criteria, and that were therefore off before the previous inversion. This recognizes that relatively small portions of the blood pool that may not have the requisite intensities to meet the final thresholding criteria, but that form part of the blood pool nonetheless, for example backflow within the blood pool, properly assume a portion of the final output image.

The net result of the two inversions, therefore, is to turn on those small groups of pixels disposed within the endocardial boundary. Accordingly, referring to an accurate representation of the blood pool is produced, the outer periphery of which defines the contour of the endocardial boundary. Additionally, the MR image corresponding to the output mask may also be output to the user. If desired, the outer boundary of the image may be smoothed before outputting the output mask to the user. One method of smoothing the boundary of an image is disclosed in a U.S. patent application, filed on even date herewith, and entitled Method and Apparatus for Fitting a Smooth Boundary to Segmentation Masks, the disclosure of which is hereby incorporated by reference.

EXAMPLE OF THE PREFERRED EMBODIMENT

Referring now to Figs. 13 and 14, data acquired while carrying out the endocardial segmentation process is illustrated for iterations 2-13. It is evident that, at iteration 13, the average intensity for the ring increased, as did the standard deviation. This indicates that the expansion boundary has traversed the endocardium and entered surrounding tissue, such as the myocardium, epicardium, and surrounding tissue. Accordingly, at iteration 13, because Mean_3_Old is greater than 0, and less than Mean_3, Mean 1 is updated to 74.04 during the final refinement process 246. The mask is updated, and an output mask illustrated in Fig. 15 is provided demonstrating

the blood pool 172, whose outer contour defines the endocardial boundary 173.

The invention has been described in connection with what are presently considered to be the most practical and preferred embodiments. However, the present invention has been presented by way of illustration and is not intended to be limited to the disclosed embodiments. Accordingly, those skilled in the art will realize that the invention is intended to encompass all modifications and alternative arrangements included within the spirit and scope of the invention, as set forth by the appended claims.

CLAIMS

What is claimed is:

1. A method for segmenting an image acquired with a medical imaging system to identify the boundary of an organ, comprising:

A. acquiring image data of said organ with said medical imaging system;

B. reconstructing an image corresponding generally to said organ;

C. selecting a starting location on said reconstructed image within the confines of said boundary of said organ;

D. iteratively propagating an expansion boundary around said starting location outwardly a plurality of times until it is determined that said expansion boundary has traversed said boundary of said organ; and

E. outputting a representation of said boundary of said organ.

2. The method as recited in claim 1, wherein step (C) further comprises selecting a point on said reconstructed image corresponding to said image data and having a relatively high intensity.

3. The method as recited in claim 1, wherein step (D) further comprises acquiring statistical data corresponding to said expansion boundary after each iteration.

4. The method as recited in claim 3, further comprising determining that said expansion boundary has traversed said boundary of said organ based on said statistical data, wherein said statistical data includes a standard deviation of intensity values of said image data corresponding to said expansion boundary.

5. The method as recited in claim 3, further comprising determining that said expansion boundary has traversed said boundary of

said organ based on statistical data including the size of said expansion boundary, and a standard deviation of intensity values corresponding to said expansion boundary.

6. The method as recited in claim 1, wherein step (D) further comprises, subsequent to each iteration:

a. refining said reconstructed image to remove any fine lines and clusters of pixels not connected to said starting location;

b. producing said expansion boundary as an outer boundary of said reconstructed image; and

c. calculating statistics pertaining to said expansion boundary; and;

d. based on said statistics, determining when said expansion boundary has traversed said boundary of said organ.

7. The method as recited in claim 1, further comprising:

F. refining said reconstructed image prior to outputting said representation of said boundary of said organ.

8. The method as recited in claim 7, wherein step (F) further comprises:

a. turning on all pixels on said reconstructed image having an intensity value greater than an intensity of said expansion boundary during a previous iteration;

b. removing any fine lines and clusters of pixels not connected to said starting location;

c. mapping said reconstructed image onto an output image; and

d. turning on any pixel clusters within said expansion boundary that are smaller than a predetermined threshold.

9. The method as recited in claim 1, further comprising:

F. determining that an error condition exists when at least one of the following conditions are met;

1. the size of said expansion boundary has exceeded a maximum threshold and said expansion boundary has not been determined to have traversed said boundary of said organ; and

2. a maximum number of iterations have been performed and said expansion boundary has not been determined to have traversed said boundary of said organ.

10. The method as recited in claim 1, wherein said boundary of said organ is a left ventricular endocardium of a human heart.

11. A magnetic resonance imaging system for producing an image of an outer boundary of an organ, comprising:

means for acquiring NMR image data of said organ;

means for reconstructing an image corresponding generally to said organ;

means for selecting a starting location on said reconstructed image within the confines of said boundary of said organ;

means for iteratively propagating an expansion boundary around said starting location outwardly a plurality of times until it is determined that said expansion boundary has traversed said boundary of said organ; and

means for outputting a representation of said boundary of said organ.

12. The magnetic resonance imaging system as recited in claim 11, wherein said means for selecting further comprises means for selecting a point on said reconstructed image corresponding to said image data and having a relatively high intensity.

13. The magnetic resonance imaging system as recited in claim 11, further comprising means for acquiring statistical data corresponding to said expansion boundary after each iteration.

14. The magnetic resonance imaging system as recited in claim 13, wherein said means for acquiring statistical data further comprises means for determining that said expansion boundary has traversed said boundary of said organ based on said statistical data, wherein said statistical data includes a standard deviation of intensity values of said image data corresponding to said expansion boundary.

15. The magnetic resonance imaging system as recited in claim 13, wherein said means for acquiring statistical data further comprises means for determining that said expansion boundary has traversed said boundary of said organ based on statistical data including the size of said expansion boundary, and a standard deviation of intensity values corresponding to said expansion boundary.

16. The magnetic resonance imaging system as recited in claim 11, further comprising means for determining that an error condition exists when one of the following conditions are met;

1. the size of said expansion boundary has exceeded a maximum threshold and said expansion boundary has not been determined to have traversed said boundary of said organ; and

2. a maximum number of iterations have been performed and said expansion boundary has not been determined to have traversed said boundary of said organ.

17. The magnetic resonance imaging system as recited in claim 11, wherein said outer boundary of said organ comprises a left ventricular endocardium of a human heart.

METHOD AND APPARATUS FOR EXTRACTING A LEFT VENTRICULAR ENDOCARDIUM FROM MR CARDIAC IMAGES

ABSTRACT OF THE INVENTION

A method and apparatus is provided for segmenting a left ventricular endocardium in a magnetic resonance image. Image shape, size, gradients, intensity, and connectivity are used to locate the endocardial boundary. Specifically, a series of dilations and refinements to a mask corresponding to acquired data is performed. Variations in intensity, representing the endocardial boundary, are detected, and the endocardial boundary may then be clearly identified in the MR image.

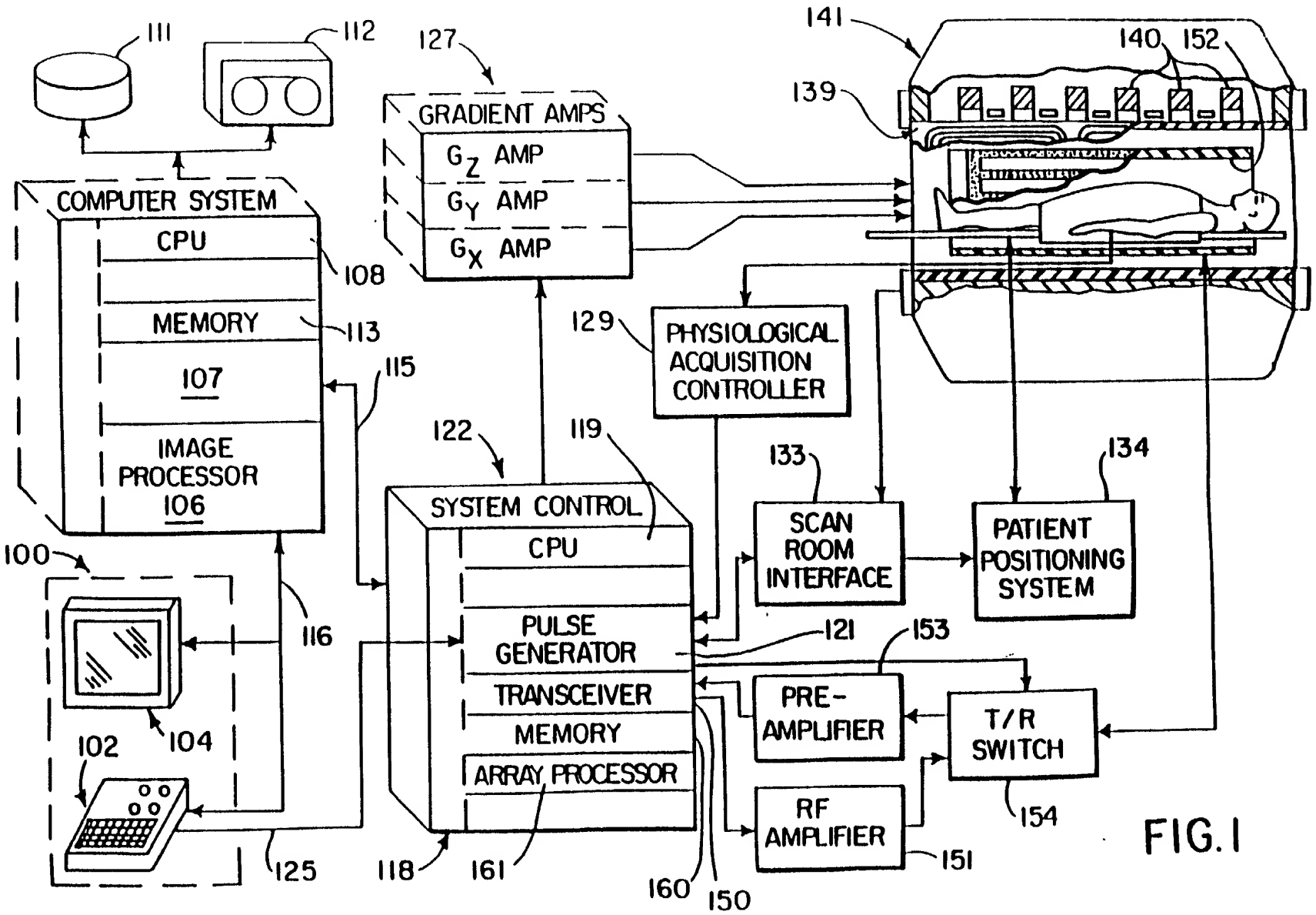

FIG.1

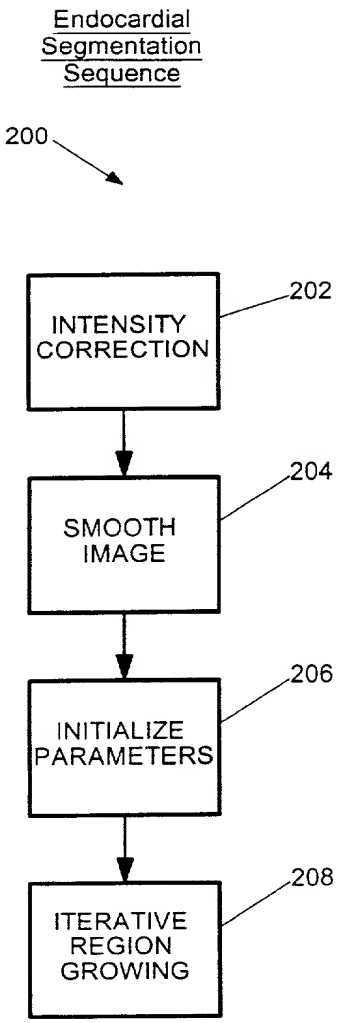

Fig. 2

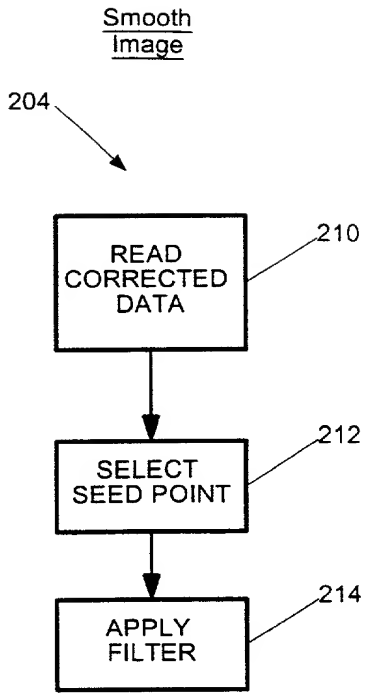

FIG. 3

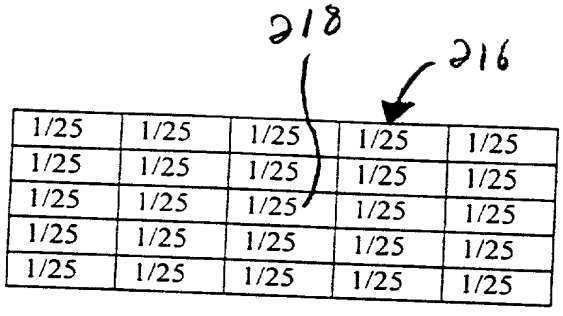

Fig. 7

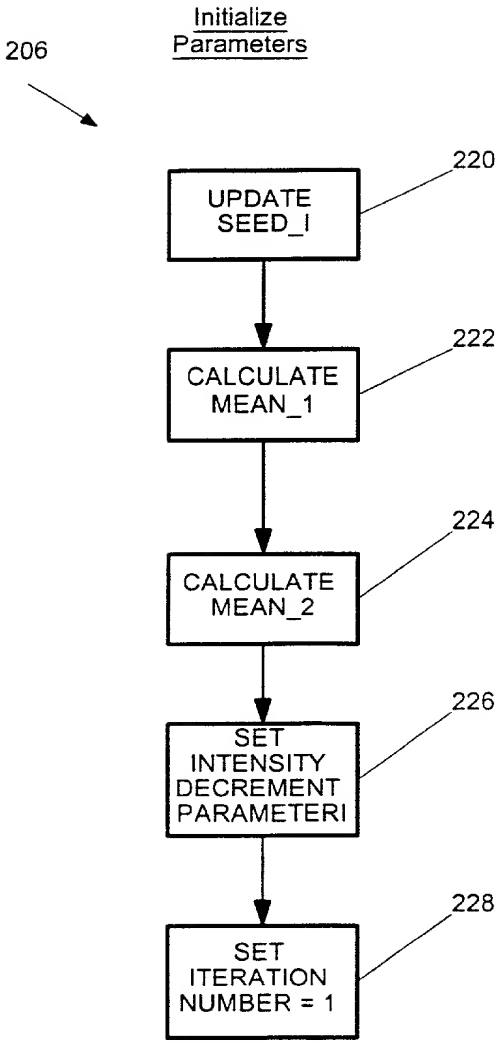
206
Initialize Parameters
UPDATE SEED_I
220
CALCULATE MEAN_1
222
CALCULATE MEAN_2
224
SET INTENSITY DECREMENT PARAMETERI
226
SET ITERATION NUMBER = 1
228

FIG. 4

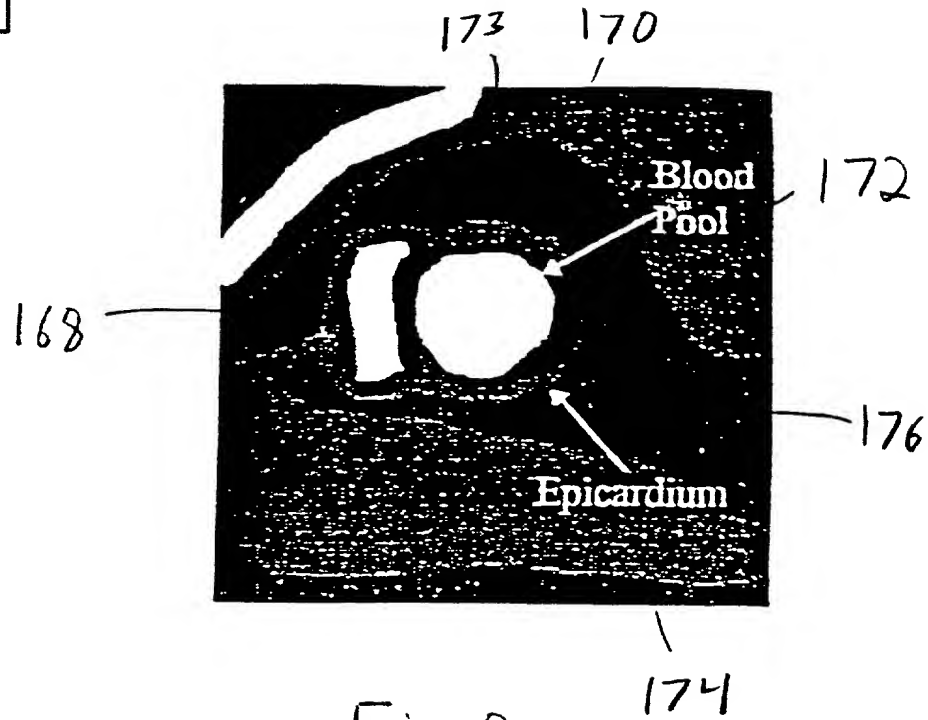
173
170
Blood Pool
172
168
176
Epicardium
174

Fig. 8

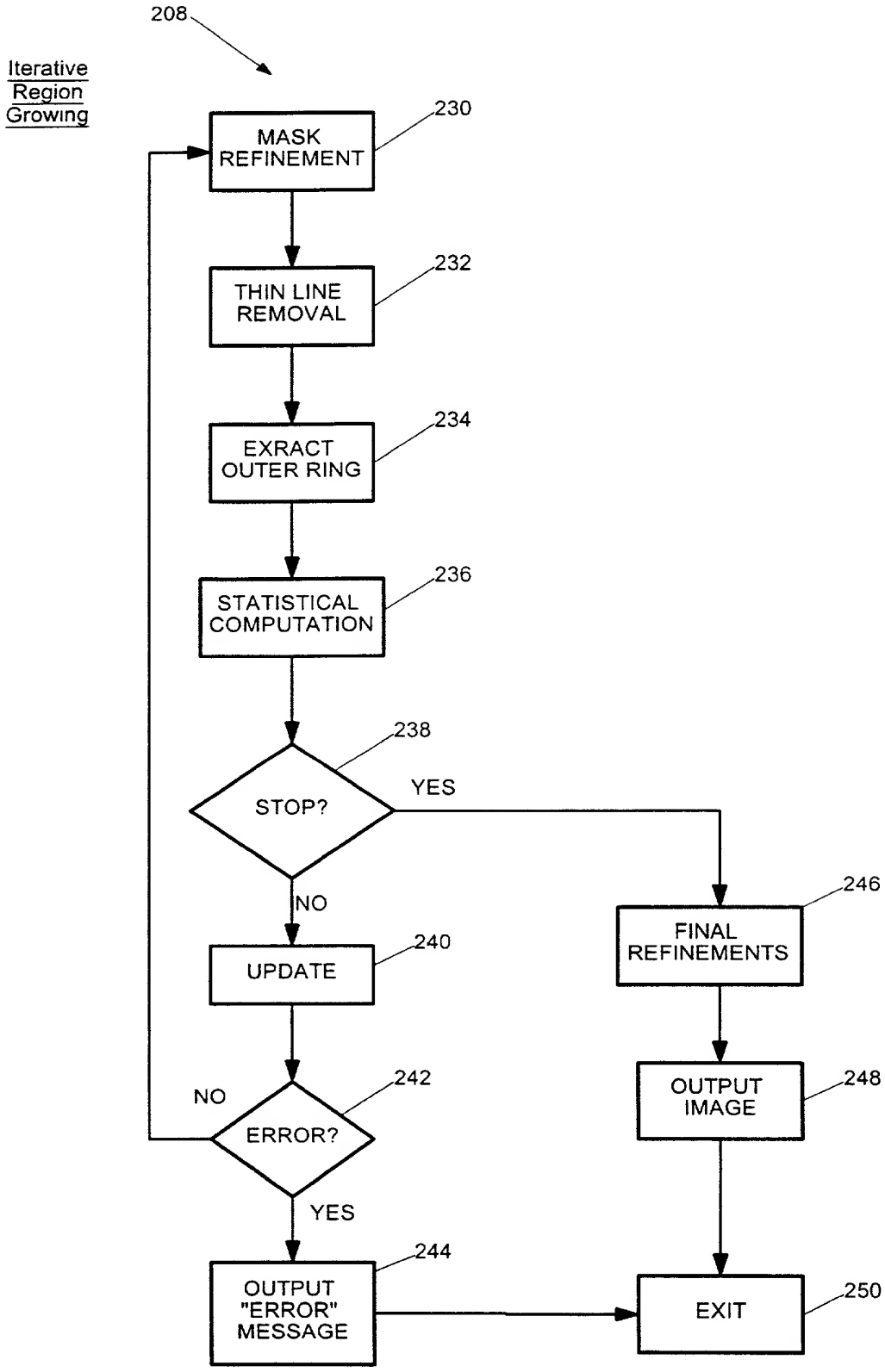
208
Iterative Region Growing
MASK REFINEMENT
230
THIN LINE REMOVAL
232
EXRACT OUTER RING
234
STATISTICAL COMPUTATION
236
STOP?
238
YES
NO
UPDATE
240
ERROR?
242
NO
YES
OUTPUT "ERROR" MESSAGE
244
FINAL REFINEMENTS
246
OUTPUT IMAGE
248
EXIT
250

FIG. 5

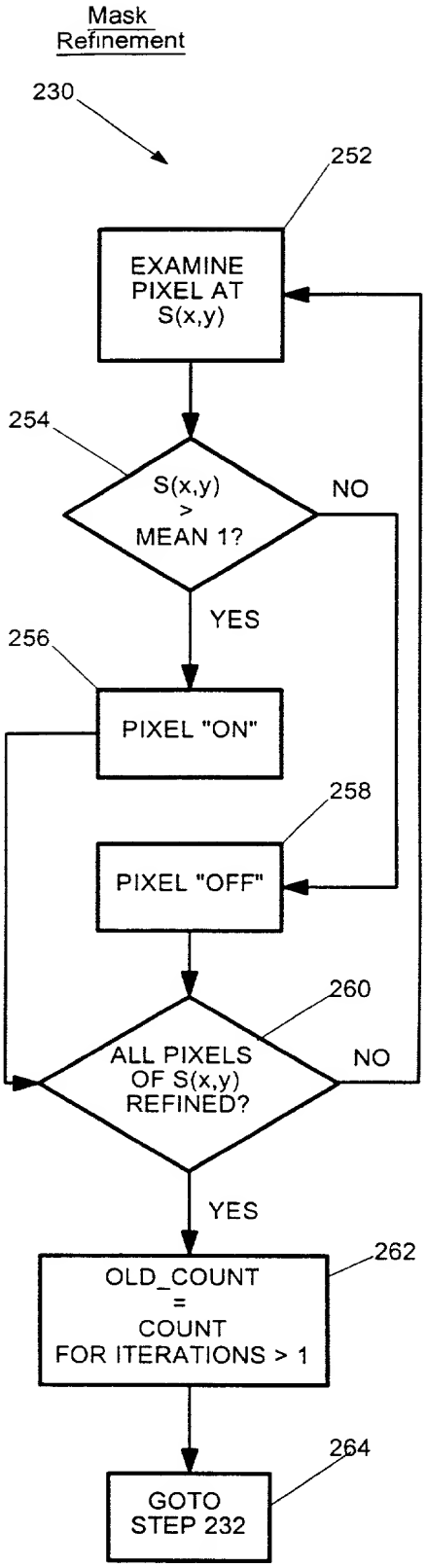
Mask Refinement
230
252
EXAMINE PIXEL AT S(x,y)
254
S(x,y) > MEAN 1?
NO
YES
256
PIXEL "ON"
258
PIXEL "OFF"
260
ALL PIXELS OF S(x,y) REFINED?
NO
YES
262
OLD_COUNT = COUNT FOR ITERATIONS > 1
264
GOTO STEP 232

FIG. 6

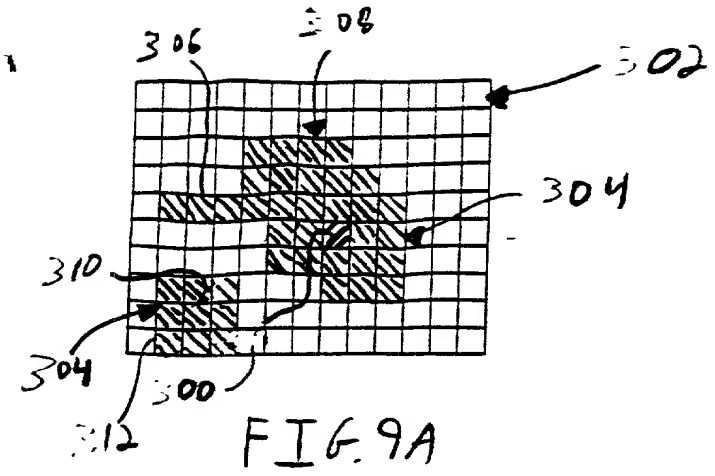

FIG. 9A

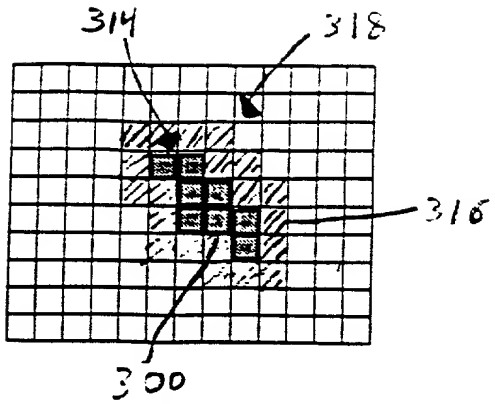

FIG. 9B

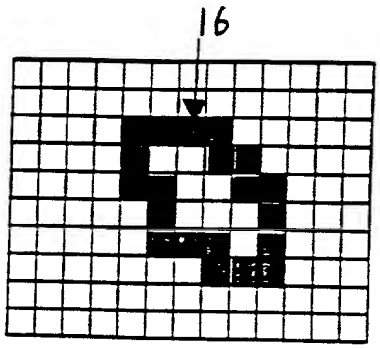

FIG. 9C

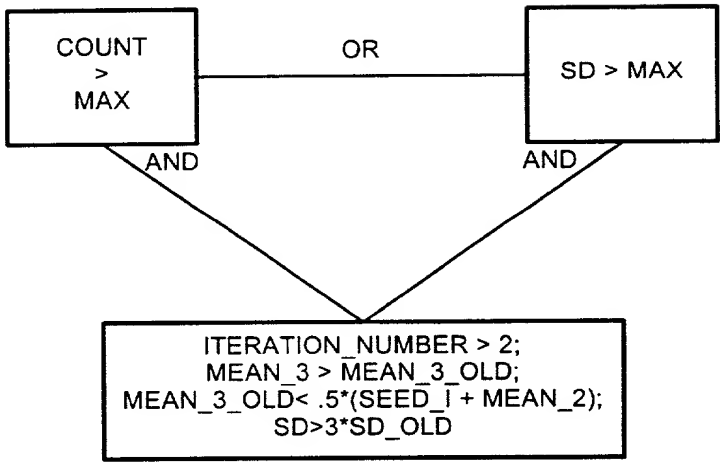

FIG. 11

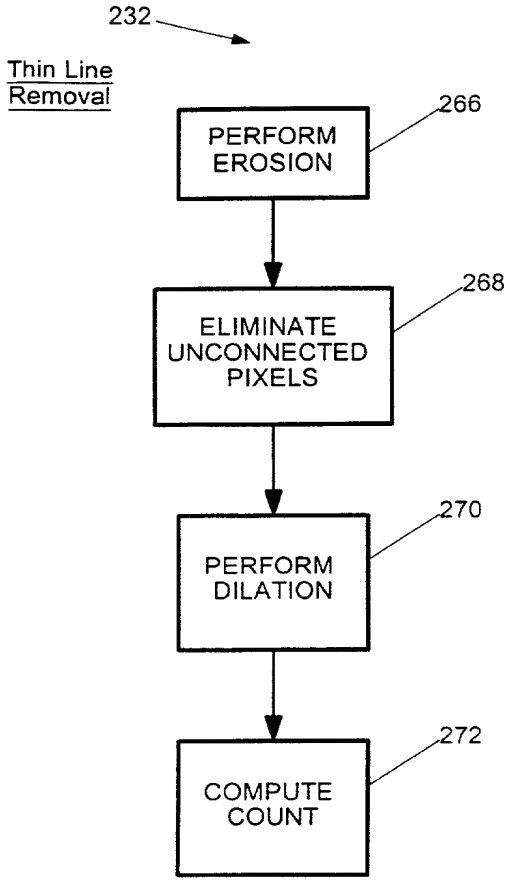

FIG. 10

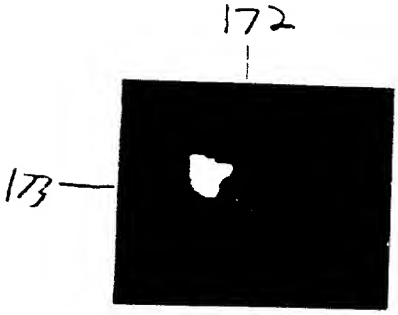

FIG. 15

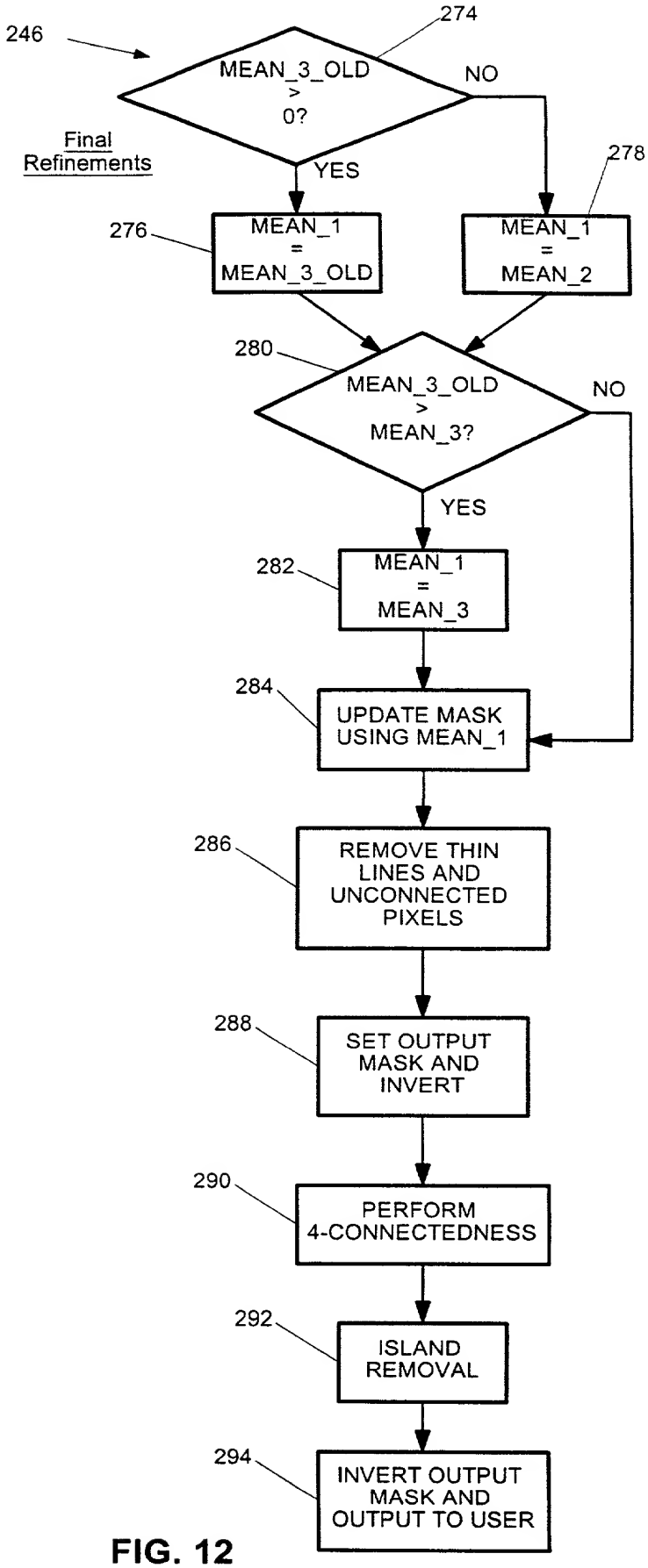

FIG. 12

Iteration	Count	Mean1	Mean2	Mean3	SD
2	28	150.09	72.48	0	0
3	104	142.19	72.48	146.48	2.48
4	147	134.3	72.48	137.76	2.25
5	181	126.4	72.48	130.44	2.26
6	210	118.5	72.48	122.9	2.2
7	252	110.59	72.48	114.95	3.09
8	287	102.69	72.48	105.7	2.6
9	333	94.8	72.48	97.65	2.66
10	384	86.9	72.48	89.27	2.51
11	439	79.0	72.48	82.05	1.86
12	549	71.09	72.48	74.04	2.28
13	6956	63.19	72.48	88.41	16.88

FIG. 13

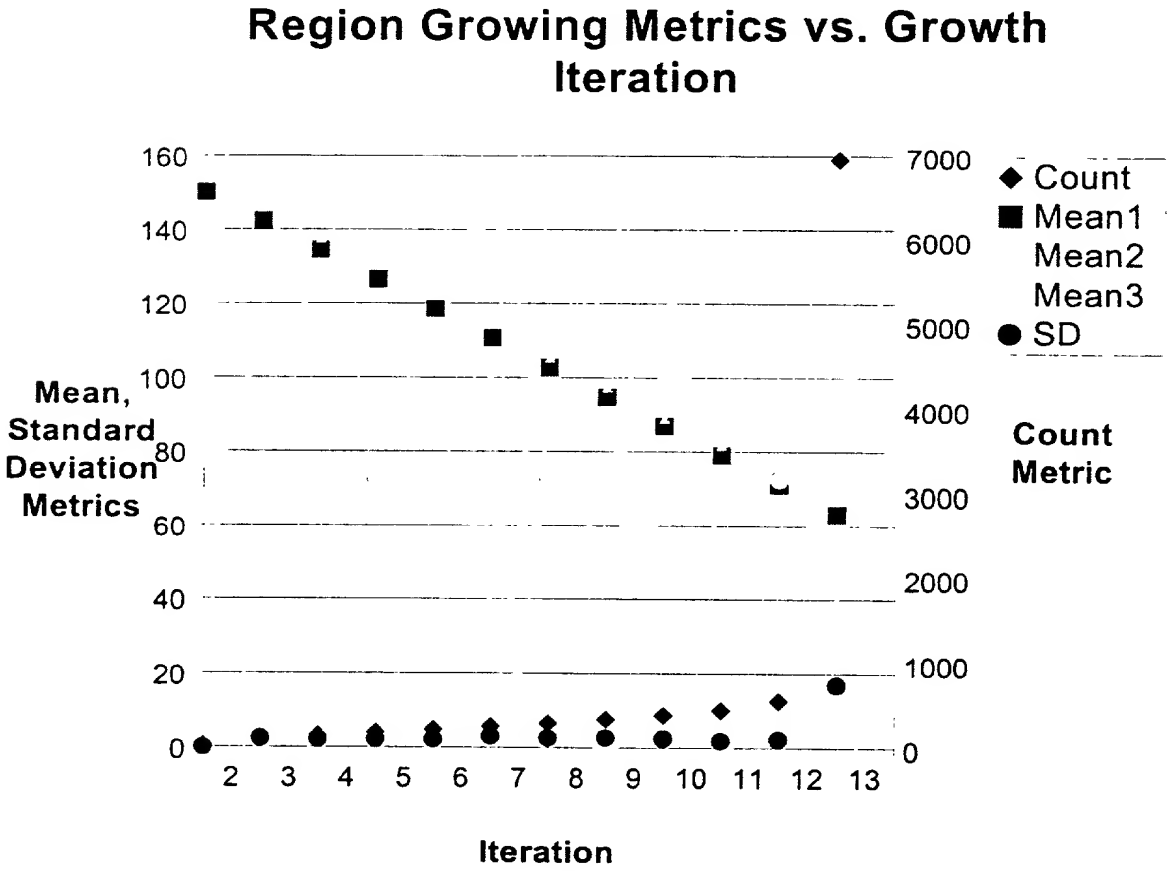

FIG. 14

EXPRESS MAIL LABEL NO. EJ 636 886 711 US

PTO/SB/01 (6-95)
Approved for use through 9/30/98. OMB 0651-0032
Patent and Trademark Office: U.S. DEPARTMENT OF COMMERCE

Please type a plus sign (+) inside this box [+]

0010/PTO Rev. 6/95 — U.S. Department of Commerce Patent and Trademark Office

DECLARATION FOR UTILITY OR DESIGN PATENT APPLICATION

[ ] Declaration Submitted with Initial Filing OR [X] Declaration Submitted after Initial Filing

Attorney Docket Number	390086.94677
First Named Inventor	Gopal B. Avinash
COMPLETE IF KNOWN	
Application Number	
Filing Date	November 22, 2000
Group Art Unit	
Examiner Name	

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name.

I believe that I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

METHOD AND APPARATUS FOR EXTRACTING A LEFT VENTRICULAR ENDOCARDIUM FROM MR CARDIAC IMAGES

(Title of the Invention)

the specification of which

[X] is attached hereto

OR

[ ] was filed on (MM/DD/YYYY) _____ as United States Application Number or PCT International Application Number _____ and was amended on (MM/DD/YYYY) _____ (if applicable).

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations §1.56

I hereby claim foreign priority benefits under Title 35, United States Code §119(a)-(d) or §365(b) of any foreign application(s) for patent or inventor's certificate or §365(a) of any PCT international application which designated at least one country other than the United States of America, listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate, or any PCT international application having a filing date before that of the application on which priority is claimed.

Prior Foreign Application Number(s)	Country	Foreign Filing Date (MM/DD/YYYY)	Priority Not Claimed	Certified Copy Attached? YES	NO
			[ ]	[ ]	[ ]
			[ ]	[ ]	[ ]
			[ ]	[ ]	[ ]
			[ ]	[ ]	[ ]
			[ ]	[ ]	[ ]
			[ ]	[ ]	[ ]

[ ] Additional foreign applications numbers are listed on a supplemental priority sheet attached hereto:

I hereby claim the benefit under Title 35, United States Code §119(e) of any United States provisional application(s) listed below.

Application Number(s)	Filing Date (MM/DD/YYYY)

[ ] Additional provisional application numbers are listed on a supplemental priority sheet attached hereto.

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DECLARATION

I hereby claim benefit under Title 35, United States Code §120 of any United States application(s), or §365(C) of any PCT international application designating the United States of America, listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application or PCT international application in the manner provided in the first paragraph of Title 35, United States Code §112, I acknowledge the duty to disclose information which is material to patentability as defined in Title 37, Code of Federal Regulations §1.56 which became available between the filing date of the prior application and the national or PCT international filing date of this application.

U.S. Parent Application Number	PCT Parent Number	Parent Filing Date (MM/DD/YYYY)	Parent Patent Number *(if applicable)*

[ ] Additional U.S. or PCT international application numbers are listed on a supplemental priority sheet attached hereto

As a named inventor, I hereby appoint the following attorney(s) and/or agent(s) to prosecute this application and all continuation and divisional applications based thereon, and to transact all business in the Patent and Trademark Office connected therewith:

[ ] Firm Name _____ Customer Number or label _____

OR

[X] List attorney(s) and/or agent(s) name and registration number below

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Herbert W. Mylius	24,578	Bruce T. Neel	37,406
Barry E. Sammons	25,608	Michael A. Jaskolski	37,551
Charles W. Jirauch	26,186	Richard T. Roche	38,599
Nicholas J. Seay	27,386	Alexander B. Ching	41,669
George E. Haas	27,642	Terri S. Flynn	41,756
Michael J. McGovern	28,326	John T. Pienkos	42,997
Carl R. Schwartz	29,437	Daniel G. Radler	43,028
Keith M. Baxter	31,233	Gregory M. Smith	43,136
John D. Franzini	31,356	Steven J. Wietrzny	44,402
Janine R. Novatt	32,593	Paul D. Amrozowicz	45,264
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I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

Name of Sole or First Inventor: [ ] A petition has been filed for this unsigned inventor

Given Name	Gopal	Middle Initial	B.	Family Name	Avinash	Suffix e.g. Jr.	

Inventor's Signature _____ Date _____

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[X] Additional inventors are being named on supplemental sheet(s) attached hereto

Please type a plus sign (+) inside this box [+]

DECLARATION	ADDITIONAL INVENTOR(S) Supplemental Sheet

Name of Additional Joint Inventor, if any: ☐ A petition has been filed for this unsigned inventor

Given Name	Matthew	Middle Initial	W.	Family Name	Turek	Suffix e.g. Jr.	

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Given Name		Middle Initial		Family Name		Suffix e.g. Jr.	

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Residence		State		Country		Citizenship	

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